EVALUATION OF INFRARED-SENSITIVE FILM FOR DETERMINATION OF SPECTRAL QUALITY WITHIN A FOREST CANOPY[1]

BRADLEY W. FLOYD[2] AND REGINALD D. NOBLE, Department of Biological Sciences, Bowling Green State University, Bowling Green, Ohio 43403

Abstract. Kodak Ektachrome Infrared film was evaluated in terms of its potential use for qualitative spectral information on solar radiation within plant canopies. It was found that an exposure rating of 125 (ASA) provides properly exposed images using through-the-lens metering, with infrared images of forest species in shaded areas appearing deep red (as these species reflect strongly in the infrared), while images of sunfleck illuminated species appear yellow because they reflect in the green spectral region. Infrared color film serves as an inexpensive means of supplementing spectroradiometric analysis of light within canopy systems, and provides semi-qualitative information about the source of radiation of a particular wave-length. The major limitation observed was the film's tendency to form numerous colors which, in effect, masked the primary colors.

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The light climate within a forest canopy is richer in infrared than in visible wavelengths (Coombe, 1957; Anderson, 1964; Reifsnyder and Lull, 1965; Vezina and Boulter, 1966; Floyd, 1973). In recent years, evaluation of the woodland light climate has been facilitated by the development of spectroradiometry as discussed by Norris (1966). Spectral distributions in coniferous forests were determined spectroradiometrically by Freyman (1968) and Atzet and Waring (1970) and in hardwood forests by Ewel (1970). Spectroradiometric analysis is precise but the initial cost of the instrumentation is high, especially for the investigator who wishes only qualitative spectral information.

Black and white infrared film has had many ecological applications. It has been used in the detection of diseased trees (Colwell *et al*, 1966), in other plant pathology applications (Bawden, 1933; Babel, 1935) and in aerial ecological surveys (Ives, 1939). Color infrared film was found to be more effective than black and white infrared film in the photo-interpretation of forest species (Howard, 1970; Heller *et al*, 1966; Wilson, 1960) because changes in the red to infrared wavelengths produce only tonal differences in black and white while on color film, such changes result in color differences.

Color infrared film has been utilized in crop surveys (Colwell *et al*, 1966), the evaluation of stress conditions on citrus groves (Norman and Fritz, 1965), and in the detection of insect infestation in pine plantations (Heller *et al*, 1966). McCree (1968) describes a method for spectral measurements under plant canopies utilizing color infrared film (Kodak Ektachrome Infrared Aero Film, Type 8443). The type of film evaluated by McCree has since been modified and its color sensitivity increased (Kodak, 1972). The newer color infrared film (Kodak Ektachrome Infrared Film) comes in 135-size cartridges (20 exposures) and can be processed via Kodak Process E-4. It is the purpose of this study to evaluate infrared film as a tool for qualitative estimates of spectral composition of radiation within a forest canopy.

MATERIALS AND METHODS

Kodak Ektrachrome Infrared film (35 mm) with an ASA rating of 100 was stored at 0° C

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Present address: Environsphere Inc., 19 Recter St., N.Y., N.Y. 10006.

and allowed to warm to ambient temperature prior to use. This film, in contrast to standard color reversal film, has three image layers which are sensitive to the green, red, and infrared spectral regions, rather than blue, green, and red regions. A Kodak Wratten No. 12 gelatin filter was used on the camera to reduce the blue spectral region, to which these layers are also sensitive. Exposed and processed the film gives yellow positive image records in the green-sensitive layer, and magenta and cyan images appear in the red- and infrared-sensitive layers, respectively. The infrared sensitivity range of the film is reported as 700–900 nm. Numerous colors may be produced in the processed transparency, depending on the energy distribution in the green, red, and infrared spectral regions, and on reflectance and transmittance properties of the subject. Green leaves record red because they strongly reflect infrared. This produces a light-toned cyan image, which allows red from other image layers to predominate (Kodak, 1972).

Ten rolls of film were exposed with Nikon F2 and Nikkormat FTn cameras using 35 mm, 50 mm, 55 mm, or 135 mm lenses to render images at different angles of view. No exposure variation was observed between the different lenses. Accurate focus was obtained by first focusing the image, then setting the distance scale to the infrared calibration mark on the lens. Nikon Y52, polar, Vivitar 25A filters (52 mm, screw in) and a Kodak Wratten No. 12 gelatin filter were used singly and in various combinations. For the most part, the Nikon Y52 was used because it most closely approximated the Kodak Wratten No. 12 filter.

Exposure determinations were made via the through-the-lens metering system on each camera, as well as with a Gossen Luna Pro hand-held exposure meter in both the reflected and incident light modes. Indicated exposures were bracketed by ±1-½ f stops at ½-stop intervals. Exposure readings from the hand-held meter were corrected by the appropriate filter factor. On separate occasions, exposures were made (between 11:00 a.m. and 1:00 p.m.) of canopy, sub-canopy, and herbaceous species found in shaded and sunfleck illuminated areas. Close-ups were also taken of green leaves damaged by disease and/or insects and predominant leaf litter. Control conditions were provided by exposing Kodak Ektachrome X color transparency film concurrently with the infrared film. The resulting transparencies were evaluated according to shades of and differentiation between yellow, magenta, and cyan images as governed by exposure determination and filter combinations.

RESULTS AND DISCUSSION

The type of metering used, as well as the ASA rating of the film, was found to be critical in terms of obtaining properly exposed transparencies. At an ASA rating of 100, the hand-held meter (reflected light mode) computed exposures which gave excellent image tone as well as color saturation, while use of through-the-lens metering consistently resulted in overexposed images with poor to good image tone and color saturation. Underexposure of ½ stop corrected this condition, however, underexposure of more than a ½ stop resulted in loss of image detail and color differentiation. This might be expected since Kodak suggests that exposure latitude for this film is plus or minus ½ stop. The use of an ASA rating of 125, as suggested by Rothschild (1975), is an alternate method of obtaining properly exposed transparencies using through-the-lens metering.

The choice of filtration to eliminate blue light, to which the film is sensitive, did not appear to be critical. A comparison of the filtering effect of a Nikon Y52 filter with the recommended Kodak Wratten No. 12 filter resulted in little or no difference. The Kodak Wratten No. 12 appeared to be a slightly deeper yellow (cutting out more blue) than the Y52, and the resulting cyan images were of a deeper blue than those recorded with the Nikon filter. In view of the higher cost of adapting to gelatin filters, a moderate to deep yellow filter of the less expensive screw-on variety is adequate for general infrared color film work.

The use of a blue cutoff filter can indeed be critical, depending on the wavelengths to be evaluated. Cyan color in a transparency was masked when the blue cutoff filter was not used, but little or no change was observed in the magenta image, either in hue or differentiation from the other colors, when the filter was omitted. For example, exposures taken of canopy species under clear skies, depicted the sky color as a blue-green with the blue cutoff filter, and as a cream color without the filter. The foliage remained a magenta color in both instances.

The combination of a 25A (deep red) filter with the Y52 resulted in a color shift. Yellow was changed to orange, and magenta to red-orange. The cyan images became a pale yellow-green. In addition, this filter combination compounded exposure problems, causing overexposure, both with through-the-lens and hand-held metering. The colors become less distinct and the cyan image, in particular, was masked due to overall yellowing of the transparency. The use of this filter to increase color differentiation during exposure is therefore not recommended. The use of color correcting filters, as recommended by Kodak, during printing of the transparency is assumed to be superior to filter combinations used directly on the camera lens.

Prior to, or in the early stages of, foliar development of canopy species the leaf litter appears to reflect mainly in the infrared. Exposures of the forest floor made during this period resulted in cyan images. Close-ups taken of the litter show that the cyan image is generally confined to specific leaves, although not along species lines. This reflectance characteristic of particular leaves is probably due to age or stage of decomposition and/or the angle of the unobstructed incident radiation. In any case, the leaf litter reflects in the infrared at a time of little or no foliar interference. This information (shown through interpretation of infrared film) is consistent with spectroradiometric data collected on the same site (Floyd, 1973).

Young expanding leaves of *Liriodendron tulipifera* showed light magenta coloration, along with patches of cyan along the leaf margins. The terminal bud scars found along the branches of *L. tulipifera* appeared as a deep cyan. From this observation it can be assumed that the non-foliar parts of the canopy species contribute (through reflection properties) to the strongly red-infrared environment found within the canopy system during the early stages of foliar development.

The infrared image coloration of understory and herbaceous species changed from a deep magenta (strong purple tint) to a red-magenta color upon completion of foliar development in the canopy species. This can be interpreted as a change in the wavelengths incident to the herbaceous species due to canopy filtration. Early in foliar development of canopy species, when most of the incident radiation reaches the understory, the leaves reflect weakly in the infrared wavelengths. Later, when canopy development is complete, the leaves appear to strongly reflect light of longer wavelengths as based on characteristics of the film (i.e., the stronger the infrared, the more red predominates in the processed transparency). Thus, the stronger reflection of the infrared spectral region by understory species appears to be a function of canopy filtration, since there is little evidence which indicates that reflectance properties of understory species is altered during canopy closure. This would suggest that the light climate beneath the completely developed forest canopy is strong in the red-infrared wavelengths, which is supported by spectroradiometric investigations (Ewel, 1970; Floyd, 1973; Reifsnyder and Lull, 1965).

Evaluation of wavelengths found in sunfleck illumination utilizing infrared color film, shows that illuminated leaves appear to reflect primarily in the green wavelengths (yellow image). Leaf litter so illuminated reflects infrared, producing a cyan image on the processed transparency. These observations correspond to those made during spectroradiometric studies.

It is felt that infrared color film can serve as a qualitative spectral estimator when general information is all that is required. Resulting transparencies should be carefully interpreted, and final conclusions based on the color characteristics of the film. The formation of numerous colors other than the primary yellow, magenta, and cyan may prove to complicate interpretation of woodland light climates. The white card technique, introduced by McCree (1968), should definitely be included in any infrared film study as a means of assessing color characteristics of the particular roll of film or processing variations. The instances in which the film and spectroradiometric data are in accordance, together with the relatively low cost, substantiates the general applicability of this film. However, as indicated by McCree, the information obtained by infrared color film serves best as a supplement to that information obtained spectroradiometrically.

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